A COMPARISON OF METHODS OF QUADRATTING SHORT-GRASS VEGETATION [1]

By Lincoln Ellison

Range Examiner, Intermountain Forest and Range Experiment Station, Forest Service, United States Department of Agriculture

INTRODUCTION

Permanent quadrats have long been employed in range studies where it is desired to measure the progress of changes in vegetation as a result of different systems of grazing. In some studies, description of the vegetation on such quadrats is effected by means of charts showing the position and extent of each plant; in other cases, estimates of the basal area of the vegetation or of its crown spread are made; in others the total weight or volume of each species is estimated; and in still others the plants are simply counted. The method to be used is determined largely by the characteristics of the vegetation; the method of counting would not be feasible with turf-forming species such as the short grasses, for example, but it might be useful in associations of single-stemmed plants.

In short-grass associations, descriptions of quadrats tend to be expressed in terms of area of ground cover, because of the low, matted habit of the principal species. There are many ways of determining area of ground cover—the first and second methods mentioned in the last paragraph are two of these. Until recently no critical comparisons have been made between methods. The present paper reports the results of a comparison made near Miles City, Mont., with the specific objectives of determining the degree of consistency of three methods and the causes of subjective error in each.

To the writer's knowledge, the only published comparisons of methods made prior to the present one were by Hanson and Love (*5*) [2] in Colorado, and by Hanson (*4*) in North Dakota. These studies emphasize the limitations of methods as affected by the growth habits of different prairie species, but do not treat of errors of estimate. More recently West (*15*) has reported on the degree of correlation between repeated estimates of the same vegetation by the density-list method as used in the Union of South Africa.

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[1] Received for publication September 4, 1941. The field work of this study was carried out at the U. S. Range Livestock Experiment Station, Miles City, Mont., where the Northern Rocky Mountain Forest and Range Experiment Station of the Forest Service conducts range investigations in cooperation with the Bureau of Animal Industry and the Montana Agricultural Experiment Station. Part of the material contained in this paper was presented to the faculty of the Graduate School of the University of Minnesota as a thesis in partial fulfillment of the requirements for the degree of master of science.

[2] Italic numbers in parentheses refer to Literature Cited, p. 614.

EXPERIMENTAL PROCEDURE

METHODS TESTED

Three methods—pantograph-chart, density-list,[3] and point-analysis—were tested. For convenience the three names are shortened in the body of this paper to "chart" for pantograph-chart, "list" for density list, and "point" for point-analysis.

The chart method, illustrated in figure 1, has been described by Hill (*6*) and McGinnies (*9*). It consists essentially of reproducing a plan view of the vegetation on cross-section paper, from which areas of the various tufts can be determined later in the office.[4]

FIGURE 1.—In charting with the pantograph, the observer (right) outlines vegetation with the pointer, and the tracing is duplicated in reduced scale on the chart.

By the list method, an improved form of which has been described by Murray and Glover (*10*), the quadrat is divided into square decimeters, and with the aid of a small sliding frame carrying cross wires (fig. 2), the number of square centimeters of vegetation per square decimeter is estimated.

[3] The term "density-list" is not a particularly happy one, since areas in square centimeters, not densities in percent, are listed. The apter term "area-list" has already been used (*5*) to denote a method by which areas of separate tufts are recorded; therefore "density-list" is adopted for the present comparison. With a listing unit of 100 cm.², as used in this comparison, the two terms come to the same thing.

[4] Records by the chart method differ from those obtained by other methods in that single shoots or very small tufts are marked by spot symbols and stolons by lines, whereas by the list and point methods such small bits of vegetation are converted directly into terms of area. In order to be able to make such a conversion from the quadrat charts, each observer was asked to submit his independent estimate of the number of spots and length of stolon which he considered equivalent to a square centimeter. The estimates were closely similar, and they have been averaged in reducing the data on the charts to an areal basis. Because the outlining of very small areas by pantograph is time consuming and seldom successful, on account of play in the instrument, tufts which in the observer's judgment were between 0.5 and 1.5 cm.² in area were drawn in by the recorder as areas of 1 cm.² These conventions probably tend to reduce somewhat the variation between observers using the chart method. In order to minimize mechanical errors the same pantograph was used for all trials on any one quadrat. Two were used, both of the type shown in figure 1, described by Pearse et al. (*11*).

The method of point-analysis [5] which has been employed by New Zealand workers since 1925 (*2*, *7*, *8*), and was here adapted for use on quadrats, is a record of the proportion of evenly spaced, vertically projected pin points which strike vegetation. Thus, if 100 such points are projected downward over an area of 400 cm.^{2}, and 10 strike grass while 90 strike bare ground, the estimate will be that the density of the grass is 10 percent or that 40 cm.^{2} of the 400 is grass. The essential apparatus is shown in figure 3. A series of holes in the horizontal rack enables the observer to look down along each pin, materially increasing his certainty whether a hit is made, and revealing at a glance whether a hit is impossible.

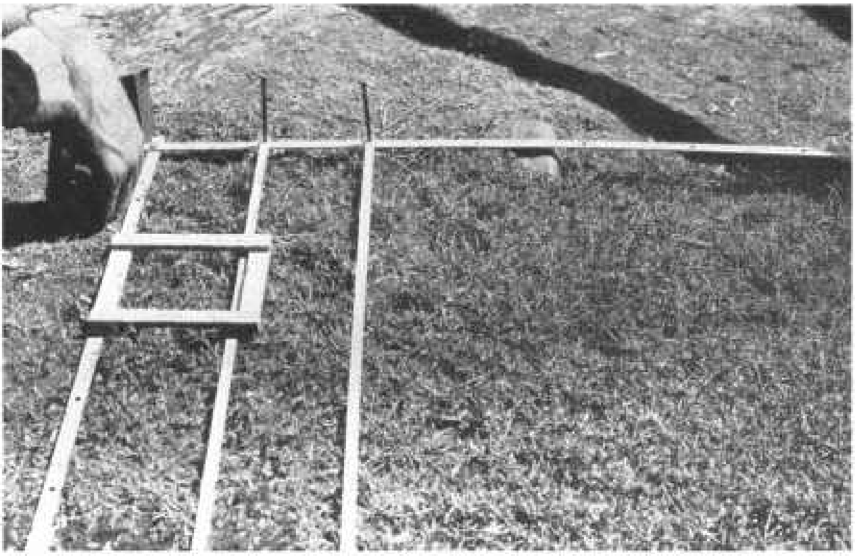

FIGURE 2.—The sliding density-list frame encloses a square decimeter divided into 25 equal parts by cross wires. Within it an estimate is made of the number of square centimeters filled with vegetation. In practice the straps dividing the quadrat into decimeter strips are offset to compensate for their width.

The point method gives an estimate of the amount of vegetation by a sampling process; consequently a portion of the observed variation may be attributed to sampling errors as well as to variations in judgment between observers. Variations in results by either chart or list method, if the area estimated be constant, may be attributed almost wholly to variations in judgment.

SELECTION OF QUADRATS

Three quadrats of varying density were selected for the test (fig. 4). Quadrat 1 (1 by 0.5 m.) had a sparse cover of blue grama grass (*Bouteloua gracilis*) in small, somewhat scattered, and fairly well-defined tufts. Quadrat 2 (0.5 by 0.5 m.) supported a denser stand of mixed

[5] The point-observation-plot method, a term introduced in 1936 by Stewart and Hutchings (*14*) to describe a large-scale estimate method, has no connection with this.

grama and buffalograss (*Buchloë dactyloides*) in larger, less well-defined tufts. Quadrat 3 (0.5 by 0.5 m.) supported a high density of buffalograss forming a matted turf with no clear distinction as to tufts.

Other species on the quadrats were negligible and are omitted from the computations that follow. The two major species are so similar in growth form that they have been regarded as one in this purely quantitative test. Tufts of buffalograss lacking stolons and inflorescences are frequently confused with grama, even by trained field men.

Quadrats smaller than the customary square meter were selected because experience has shown that if 3 meter-square quadrats were to

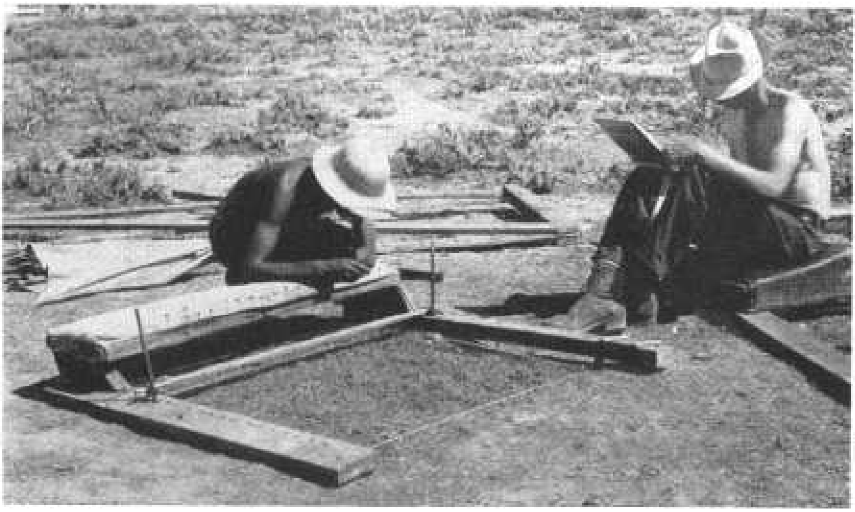

FIGURE 3.—With the point analyzer set up at the rate of 400 points per square meter the observer (left) pushes sharpened pins down onto the quadrat one by one, and calls the hits. Then the rack is moved to the next pair of holes in the baseboards and the process is repeated.

be estimated 4 times by 5 men using 3 methods—a total of 180 estimates—the area of grass might undergo appreciable change during the time required. More rapid estimates could be made on smaller quadrats. The question naturally arises: Can estimates on a smaller quadrat be considered comparable to estimates on an entire square meter? A partial answer was found in the charts of a meter-square quadrat, made the previous year by 5 men. On this quadrat of mixed grama and buffalograss the observers' estimates varied from 2,229 to 4,678 $cm.^2$ Breaking each chart into quarters and expressing the area of vegetation on each quarter in percent, it is evident, as shown by table 1, that although the estimates varied widely, the observers were fairly consistent from quarter to quarter. There is reason to suppose, therefore, that if only a quarter of the square meter had been charted the relative differences between men would have been similar to those observed on the entire quadrat.

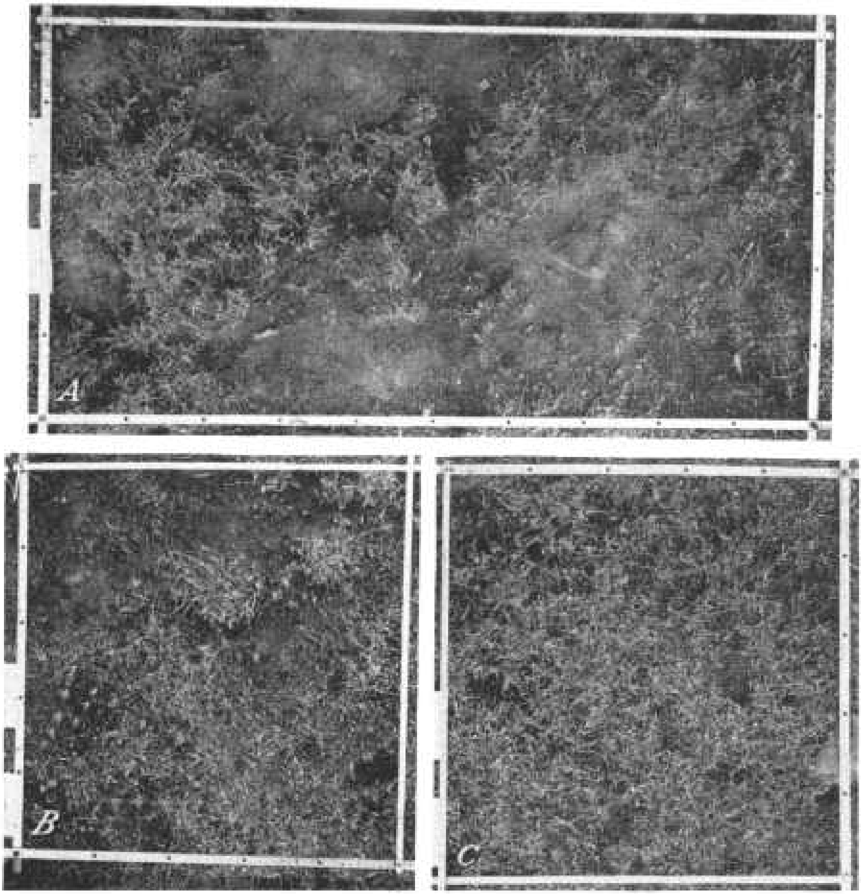

FIGURE 4.—The three quadrats used in the test. *A*, Quadrat 1, double the size of the others, mainly blue grama. *B*, Quadrat 2, predominantly buffalograss, with some grama. The prominent tuft 12 cm. from north edge, center, is grama; buffalograss, such as the tuft to the right of this, can be distinguished by stolons. *C*, Quadrat 3, practically pure buffalograss.

TABLE 1.—*Comparison of independent observers' estimates by quarter quadrats, in percent of total estimated*

Observer	Northwest	Northeast	Southwest	Southeast	Total
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
I	26.2	23.1	24.2	26.5	100.0
J	26.0	23.8	24.6	25.6	100.0
K	27.5	25.0	23.3	24.2	100.0
L	26.2	21.3	24.6	27.9	100.0
M	26.9	22.1	25.0	26.0	100.0
Average	26.6	23.1	24.3	26.0	100.0

INSTRUCTION OF OBSERVERS

Five observers were used in the comparison. During the month prior to the test all five had been using the pantograph in regular spring field work, having been uniformly trained and supervised in its use until the writer was convinced of their competence. If the observers were most proficient in any one, it was in this, the chart method. Most of them had little previous experience at listing and point-analyzing; but a full day (July 2) was given to preliminary trials and instructions in both methods, and it was felt that the techniques were mastered. In the course of these practice trials, standards of judgment in use of the list method were probably influenced by the results obtained in point-analyses. Inasmuch as almost any standard can be adopted for visual estimates, the later similarity in results by the two methods may be due to this fact.

It is manifestly impossible to say that these five observers constituted a representative sample of field assistants. The writer is confident that in ability they were at least not below average; they were all intelligent, well trained, and conscientious. Two were university graduates and three were students. To assume that the observed variability is due to incompetent personnel, then, is not so reasonable as to assume that some such variability may be expected in other, similarly high-grade assistants. It is noteworthy that one of the most experienced of the five men tended to make the most variable observations, and one of the least experienced the most consistent observations. The writer is led to suspect that variability in performance is closely associated with temperamental qualities.

An unavoidable limitation of the study was that the men knew they were being tested. Even though they were instructed not to let this consideration affect their work, and the writer believes they honestly tried to comply, it is scarcely to be expected that their results were wholly unaffected. A condition imposed in the trials was the rotation of recorders, so that in the first four trials no recorder accompanied an observer for more than one complete round of observations. That each man had to act both as recorder and observer was almost unavoidable. Only five men were available, and it was considered more advantageous to have five observers than to sacrifice two for full-time recorders, even though the use of five men did involve a greater risk of standardizing results. Care was taken to avoid making comparisons during the period of field work. Recorders were instructed not to compile any totals or to study the data or to comment about them in any way. It might be supposed that under some circumstances an observer's results would vary with different recorders, but such an effect is not discernible in the data from this study.

NUMBER AND NATURE OF TRIALS MADE

The purpose in having several trials on each quadrat by each man using each method was to obtain an estimate of the variability of individual observers. Circumstances which will be described prevented the attainment of this estimate of what biometricians call pure error.

In order to avoid effects of memory—which if operative would tend to reduce variability and the estimate of error—each quadrat was approached from a different side at each trial. While it is not possible to evaluate the success of this device, the observers were of the opinion that memory did not affect their work.

The original plan required each observer to make four trials of each method on each quadrat. Actually, six trials were made of the point method, the first four corresponding in time to the four trials by the chart and list methods. For the first two trials of the point method 400 points per square meter were projected. Fearing that this rate might not be sufficiently intensive to give the method a fair test, it was doubled, with the points still evenly spaced. Four trials were made at the 800-point rate, the first two corresponding in time to the last two trials by the chart and list methods. Records were kept in such a way that the pattern of points at the lower rate could be accurately segregated from these four trials. Data are therefore available for six independent trials at the lower rate as well as four at the higher rate. The additional trials complicate analysis somewhat, especially since the first two trials were at a lower rate than the last four.[6]

To have the work completed quickly was desirable, in order to minimize the change of vegetation with season. Trials were begun July 6 and completed July 23, 1936, covering an interval of 2½ weeks. It happens that the majority of observations in each trial fell inside a 4-day interval. There was no set sequence of methods, several trials of each being made on each day. Trial 1 corresponds roughly to July 6–9, trial 2 to July 10–13, trial 3 to July 14–17, and trial 4 to July 18–21. Trials 5 and 6 by the point method were made mainly July 22 and 23.

Ordinarily, no great change would have taken place in this period, but three unforeseen factors probably caused some fluctuation in density—drought, heat, and grasshoppers. The summer drought of 1936 was one of the most severe on record, and in order to have green grass on the quadrats it was necessary to water them. The countryside was suffering a grasshopper plague, and the small islands of green grass attracted grasshoppers by hundreds. Poisoning was of no avail, and finally it was necessary to place frames covered with screen or stretched burlap over the quadrats whenever they were not being worked. Intense heat, together with shade and moisture under the frames, probably resulted in forcing the grass; on the other hand, repeated handling of the vegetation, even though with great care, and a certain number of grasshoppers that somehow always managed to get under the frames, were more or less compensating factors. Judging from a series of photographs made July 9 and 21, there was not much change in the vegetation. On quadrat 1 vegetation may have been slightly denser and on quadrats 2 and 3 slightly sparser at the beginning of the trials than at the end.

This explanation is necessary in order to make clear the complexity of the factor trials. The variation between trials proved to be considerable, and it may be wondered whether it should be attributed to a progressive trend in observers' judgment or to alterations in vegetation. Apparently any great change in vegetation must be ruled out.

EXPERIMENTAL RESULTS

The source data, expressed in square centimeters of vegetation per square meter, are given in table 2. In order to study possible inter-

[6] In the tables of source data the results of each 800-point trial are split and expressed as two separate 400-point values. The 800-point value may be obtained by averaging each pair. Unless otherwise specified, trials 1 and 2 and the corresponding halves of trials 3 and 4, printed in roman type, are the point data used in the ensuing discussion.

actions between factors, analysis of variance (*13*) of all the data was attempted; but the individual components of the highest order interaction, used as error, proved to be so heterogeneous, apparently because of the great differences in quadrat density, that this scheme had to be abandoned. Even when separate analyses were made by quadrats, there was some likelihood of heterogeneity among the error terms, apparently because the chart method gave results so different from the others. Consequently, analysis is restricted to the methods separately for each quadrat, and the opportunity to study interactions statistically is lost. In the following discussion only those data are combined which appear to be reasonably homogeneous.

DIFFERENCES BETWEEN QUADRATS

A study of averages by methods on the three quadrats reveals that, although results may differ markedly with method, on the average the methods bring out the relative areas of grass in much the same way. The ratios between quadrats 1, 2, and 3 are close to 1.00 : 1.71 : 2.85 for all three methods.

TABLE 2.—*Individual estimates of short-grass area on quadrats 1, 2, and 3, in square centimeters per square meter*

QUADRAT 1

Method and trial No.	Estimate by observer— B	D	E	G	L	Average
	Square centimeters	*Square centimeters*	*Square centimeters*	*Square centimeters*	*Square centimeters*	*Square centimeters*
Pantograph-chart:						
1	1,188	1,146	1,233	1,131	1,078	1,155
2	882	941	931	1,021	1,017	958
3	826	1,083	1,058	903	804	935
4	1,120	998	960	969	933	996
Average	1,004	1,042	1,046	1,006	958	1,011
Density-list:						
1	696	606	836	772	724	727
2	710	718	746	726	700	720
3	688	676	732	612	644	670
4	706	596	734	526	578	628
Average	700	649	762	659	662	686
Point-analysis: [1]						
1	950	750	850	800	550	780
2	600	700	400	450	650	560
3	1,250 *750*	750 *750*	900 *600*	750 *750*	550 *800*	840
4	700 *1,100*	450 *700*	500 *600*	600 *600*	600 *550*	570
5	550 *600*	550 *700*	550 *650*	550 *600*	550 *900*	----------
6	700 *700*	550 *650*	500 *500*	550 *750*	450 *600*	----------
Average [2]	875	662	662	650	588	688

See footnotes at end of table.

TABLE 2.—*Individual estimates of short-grass area on quadrats 1, 2, and 3, in square centimeters per square meter*—Continued

QUADRAT 2

Method and trial No.	Estimate by observer—					
	B	D	E	G	L	Average
	Square centimeters	*Square centimeters*	*Square centimeters*	*Square centimeters*	*Square centimeters*	*Square centimeters*
Pantograph-chart:						
1	1,603	1,362	2,752	1,815	1,761	1,859
2	1,507	1,352	1,835	1,947	1,782	1,685
3	1,682	1,632	1,603	1,686	1,448	1,610
4	1,871	1,654	1,584	1,979	1,716	1,761
Average	1,666	1,500	1,944	1,857	1,677	1,729
Density-list:						
1	1,140	1,188	1,344	1,376	1,444	1,298
2	1,032	1,076	1,140	1,388	984	1,124
3	1,144	1,040	1,096	1,088	1,460	1,166
4	1,144	816	1,224	920	1,112	1,043
Average	1,115	1,030	1,201	1,193	1,250	1,158
Point-analysis: [1]						
1	1,300	1,100	900	900	800	1,000
2	1,300	1,100	1,400	1,500	1,000	1,260
3	1,100 *1,200*	1,900 *1,300*	1,300 *1,200*	900 *1,200*	1,600 *1,100*	1,360
4	1,400 *1,600*	600 *900*	1,300 *1,100*	1,500 *1,200*	1,000 *1,200*	1,160
5	1,200 *1,400*	600 *900*	1,200 *600*	1,100 *1,200*	1,300 *1,300*	----------
6	800 *700*	400 *800*	600 *1,000*	1,100 *600*	500 *1,200*	----------
Average [2]	1,275	1,175	1,225	1,200	1,100	1,195

QUADRAT 3

Method and trial No.	B	D	E	G	L	Average
Pantograph-chart:						
1	3,259	3,275	4,596	3,957	2,298	3,477
2	2,464	2,092	3,798	3,088	2,936	2,876
3	2,385	2,960	2,994	2,712	2,672	2,745
4	3,105	2,890	3,082	3,697	2,063	2,967
Average	2,803	2,804	3,618	3,364	2,492	3,016
Density-list:						
1	2,280	1,656	2,760	2,556	2,384	2,327
2	1,616	1,648	1,820	1,608	2,036	1,746
3	1,940	1,284	1,968	1,312	2,064	1,714
4	1,632	1,272	1,868	1,496	1,996	1,653
Average	1,867	1,465	2,104	1,743	2,120	1,860
Point-analysis: [1]						
1	2,300	2,300	1,900	1,800	2,200	2,100
2	2,000	1,800	1,300	1,000	1,500	1,520
3	2,000 *2,400*	2,200 *2,800*	2,000 *2,000*	2,100 *2,100*	2,200 *1,700*	2,100
4	2,400 *2,700*	1,900 *2,200*	1,600 *2,000*	2,000 *2,400*	2,000 *2,300*	1,980
5	2,400 *2,800*	2,300 *1,900*	1,700 *2,200*	1,600 *2,300*	1,700 *2,200*	----------
6	1,900 *2,400*	1,400 *2,300*	1,200 *2,300*	1,900 *1,900*	1,800 *1,900*	----------
Average [2]	2,175	2,050	1,700	1,725	1,975	1,925

[1] The paired values represent separate components of the 800-points-per-square-meter rate. The upper figure, in roman type, corresponds to the 400-point rate in trials 1 and 2. Results of the 800-point rate may be obtained by averaging each pair.

[2] Average of values in roman type only, for comparison with other methods.

DIFFERENCES BETWEEN METHODS

Table 2 shows average chart values to be higher by about half than either list or point values. An examination of the individual data reveals that out of 60 cross comparisons, chart values are exceeded only four times, twice by list and twice by point values. One reason for similarity between the last two methods has already been suggested. In the data presented by Hanson and Love (*5*) in which results obtained by chart and list methods are compared, the values obtained by charting *Buchloë dactyloides* and most tufted grasses are, as here, higher. The reason is not far to seek. Few clumps of grass form a solid cover. Even when the greatest pains are taken, a pantograph can record only the larger openings, and so the numberless small ones, which aggregate a considerable area, are lumped in with the area of vegetation. But when used with care, the list and point methods do take these many small openings and marginal irregularities into account. This fact is not fully appreciated until one has worked with a point-analyzer; then he is astonished at the frequency with which a point may penetrate a dense tuft of grass without striking a single leaf.

It will be observed in table 2 that average point values are slightly higher than average list values. Is this difference significant? Table 3 analyzes the differences between individual values, and it is seen, from the probabilities given in the last line, based on *t*-tests (*3*), that observers B and D have a strong tendency toward higher point values. On the other hand, L apparently has a tendency, not quite so strong, toward lower point values. E and G show negative and positive tendencies, respectively, without marked consistency.

TABLE 3.—*Differences between individual point*[1] *and list values, in square centimeters per square meter*

Quadrat and trial No.	Differences for observer—				
	B	D	E	G	L
	Square centimeters	*Square centimeters*	*Square centimeters*	*Square centimeters*	*Square centimeters*
Quadrat 1:					
1	+254	+144.	+14	+28	−174
2	−110	−18	−346	−276	−50
3	+312	+74	+18	+138	+31
4	+194	−21	−184	+74	−3
Quadrat 2:					
1	+160	−88	−444	−476	−644
2	+268	+24	+260	+112	+16
3	+6	+560	+154	−38	−110
4	+356	−66	−24	+430	−12
Quadrat 3:					
1	+20	+644	−860	−756	−184
2	+384	+152	−520	−608	−536
3	+260	+1,216	+32	+788	−114
4	+918	+778	−68	+704	+154
Average	+252	+283	−164	+10	−136
P value [2]	.006	.04	.10	>.9	.07

[1] The full estimate is considered in each case; i. e., trials 3 and 4 are at the rate of 800 points per square meter.

[2] A *P*-value of 0.5 indicates that the departure of the average from zero is just as likely to be the result of chance as of experimental causes, a "50–50" probability; a *P*-value of 0.05, that the departure of the average would be the result of pure chance in 5 trials out of 100. In general, the smaller the *P*-value the greater the probability of significant results.

The conclusion, then, is that the slight differences between means are not the result of differences between methods so much as differences between observers; another crew with more men of "L's" temperament would presumably have produced relatively lower point values. The practical significance of this conclusion is that observers may be expected to respond differently to different methods. Biometrically speaking, there tends to be an interaction between observer and method. The existence of such an interaction is a warning against attempting to convert individual records obtained by one method into terms of some other method.

As has been noted, the point method is subject to two sources of error—personal bias (from which, if practice coincide with theory, it should be free), and errors of sampling. How big a part does each play?

Since point-analysis records were so kept that the 400 points per square meter added in the last four trials can be segregated, each of these estimates can be separated into two parts. The variations between these parts provide an estimate of sampling error, as opposed to error derived from the observer-trial interaction. From separate analyses of variance, including a break-down of quadrat 1 into north and south halves, each 0.5 by 0.5 m., table 4 is derived. In general the paired variances are strikingly similar. The variation (12 degrees of freedom) designated "interaction" is neither greater nor less, consistently, than sampling variation (20 degrees of freedom), and one is led to conclude that the errors of personal bias by the point method are of the same order of magnitude as those inevitable in sampling.

TABLE 4.—*Sampling variances as compared with interaction variances of the point method, and probabilities of significant differences in magnitude*

Quadrat	Interaction variance	Sampling variance	P
Quadrat 1:			
Entire	16,219	21,750	.69
North half	63,542	44,500	.23
South half	33,792	40,500	.62
Quadrat 2	104,417	64,750	.17
Quadrat 3	52,750	123,750	.93

A practical problem that confronts the field worker with the point method is to know what number of point projections he should use in order to attain a desired degree of accuracy. If the points were distributed at random rather than in a rigid pattern, he would expect sampling accuracy to vary in inverse proportion to the square root of the sample size. Since in practice he is dealing with a rigid rather than a random pattern, in which each projection is not completely independent of every other, what may he expect? May he utilize sampling theory at all?

If sampling theory is applicable, we should expect the variation between 800-point values in the last four trials to be smaller than that between 400-point values by the inverse of the square root of 2, or 1.41. The last two columns in table 5, with four out of six values greater than 1.41 and two smaller, give no good reason for concluding the theory other than applicable in a broad rule-of-thumb way. Hence, within the limits of this empirical test, it would seem that after some preliminary determinations one might arrive at any accuracy desired, by altering the frequency of point projection in accordance with theory.

TABLE 5.—*Effect of doubling point-analysis rate: Standard deviations from sampling by 800 and 400 points per square meter*

Quadrat No.	s_{800}	s_{400} (even)	s_{400} (odd)	$\frac{s_{400}\text{ (even)}}{s_{800}}$	$\frac{s_{400}\text{ (odd)}}{s_{800}}$
1	90.1	122.7	141.6	1.36	1.57
2	228.5	363.2	242.7	1.59	1.06
3	162.4	248.2	275.4	1.53	1.70

DIFFERENCES BETWEEN OBSERVERS

Some differences between the results of different observers are to be expected; yet, with every possible precaution taken, it is surprising how great such differences may be. For example, quadrat 3 as charted July 14 by B had 2,385 cm.^{2} of grass; but as charted on the same day by D it had 2,960 cm.^{2} or 575 cm.^{2} more. Three days later, B charted an area of 3,105 cm.^{2} on the same quadrat and D an area of 2,890 cm.^{2}, this time 215 cm.^{2} less! This example illustrates how observers tend to report results that are not only different but in many instances inconsistent.

At the same time, some rather fixed differences between observers are apparent, for, while there are many exceptions, E tended to be the highest and L the lowest man with the chart method, E the highest and D the lowest with the list method, and B the highest and L the lowest with the point method.

A summary of the significance of differences between observers, by quadrats and methods, is given in table 6, in which probabilities for the respective analyses of variance are computed with the help of Pearson's Tables of the Incomplete Beta-Function (*12*). Differences between observers are most clearly marked on quadrat 3, and least clearly marked on quadrat 2. A satisfactory explanation is lacking, except that quadrat 3, being the most difficult quadrat of the three, probably gave most opportunity for the exercise of personal judgment.

TABLE 6.—*Probabilities that differences between average areas reported by different observers and at different trials are due merely to chance*

Quadrat No.	Pantograph-chart method	Density-list method	Point-analysis method [1]		
			400(4)	800(4)	400(6)
OBSERVERS					
1	.65	.07	.14	.07	.05
2	.28	.33	.96	.57	.66
3	.04	.006	.03	.01	.006
TRIALS					
1	.009	.05	.02	.02	.002
2	.59	.11	.43	.02	.04
3	.15	.001	.003	.09	.003

[1] In the column headed 400(4), the third and fourth trials at 400 points per square meter are included with the first 2; the column headed 800(4) relates to the last 4 trials at 800 points per square meter; the column headed 400(6) includes all 6 trials at the rate of 400 points per square meter.

The data in table 7 will serve to illustrate some of the curious quirks of observers. They are selected because on two occasions each of the observers used all methods on the same quadrat the same day. Given these conditions, the same sort of variation could probably be demonstrated between any other observers. E's values by charting and listing are markedly lower on July 20 than on July 6 and his point values are almost the same. D's results, on other days than E's but similarly near the beginning and end of the work, are quite different; although he, like E, arrives at less area by listing on the later date, his areas by charting and point-analyzing are markedly higher.

DIFFERENCES BETWEEN TRIALS

On quadrats 1 and 3 results from the first trial average higher than results from later trials, and it is this difference which is reflected in the low P values for these quadrats in table 6. The likelihood of a major vegetation change, which has already been discussed, does not seem great enough to account for so sharp a difference. The writer is convinced, from taking part in the work as well as scrutinizing the results, that after the first two days, with the establishment of a work routine, there was a general swing among observers toward conservatism in estimate. This swing was by no means unanimous, but it was strong enough to produce much of the observed difference.

TABLE 7.—*Individual estimates of area of buffalograss on quadrat 3, in square centimeters per square meter, by two men, each having made all three estimates on the date given*

Observer and date	Pantograph-chart method	Density-list method	Point-analysis method
	Square centimeters	*Square centimeters*	*Square centimeters*
Observer E:			
July 6	4, 596	2, 760	1, 900
20	3, 082	1, 868	1, 800
Observer D:			
July 9	2, 092	1, 648	1, 800
17	2, 890	1, 272	2, 500

RELATIVE VALUE OF THE METHODS

Since in this comparison there is no absolute standard with which observed values may be compared, it is impossible to determine which method of the three comes nearest to giving the true values. The point method, because it is the most mechanical, might be expected to reflect vegetation area without bias, and perhaps it comes nearest of the three methods to doing so; but as the probabilities in table 6 indicate, there were consistent differences between observers using the point method, so that this expectation is not fully realized.

IN CONSISTENCY

Since we cannot know which method is most accurate absolutely, the next best thing is to know which is most consistent within itself. An appropriate measure of variability, the inverse of consistency, is the square root of the variance, or the estimated standard deviation based upon the observed values. Estimates of standard deviations in the present test, since they are based on only 20 values (30 in the next to last column in table 8), are themselves subject to considerable error and can be considered only as rough approximations.

TABLE 8.—*Standard deviations, in square centimeters of vegetation per square meter, and as percents of the respective means*

Quadrat No.	Pantograph-chart method	Density-list method	Point-analysis method [1]		
			400(4)	400(6)	800(4)
	Square centimeters	*Square centimeters*	*Square centimeters*	*Square centimeters*	*Square centimeters*
1	90	54	151	125	90
2	292	152	345	307	228
3	491	216	210	234	162
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
1	8.9	7.9	21.9	19.5	13.6
2	16.9	13.1	28.9	28.2	21.2
3	16.3	11.6	10.9	12.4	7.8

[1] In the column headed 400 (4), the third and fourth trials at 400 points per square meter are included with the first 2; the column headed 800 (4) relates to the last 4 trials at 800 points per square meter; the column headed 400 (6) includes all 6 trials at the rate of 400 points per square meter.

In discussing averages it was pointed out that densities of the quadrats, although expressed on a different level by the chart from that by the others, are reflected similarly by all methods. A pattern is discernible in table 8 which shows variability to be more complex than this. The list method has, in the main, the smallest standard deviation; that is, of the three methods it tends to be the most consistent. Variability of both chart and list methods increases from quadrat 1 to 3, but variability of the point method is greatest for quadrat 2. The standard deviations expressed as percents of the means in the lower part of table 8 do not follow these same trends, which makes it seem unlikely that increases in variability of the chart and list methods from quadrat 1 to 3 are associated altogether with increasing density. Probably the low standard deviations of chart and list methods on quadrat 1 are associated with the predominance of small, compact tufts of grass on that quadrat, estimation of which tends to be standardized. Such definite tufts were lacking on quadrat 3.

Variability with increasing density increases somewhat more markedly by the chart than by the list method. This is probably associated with the decreasing definiteness of tuft outline from quadrat 1 to 3, making charting increasingly more difficult.

The tendency toward low standard deviations by the point method on quadrat 3 is probably associated with the fact that vegetation and bare spots were well distributed over the quadrat. The distribution on quadrat 1 was better than on quadrat 2 from the viewpoint of the point analyst, since the tufts, in general, were scattered, small, and open; whereas those on quadrat 2 tended to be larger and more compact. Thus, if a certain point hit a leaf on quadrat 2 there was more chance of its next neighbor striking a leaf also (differences in density aside) than there would have been on quadrat 1; and the same is true for a strike on bare ground. In other words, there was least likelihood of correlation between successive projections on quadrat 3 and most likelihood on quadrat 2; and the greater the correlation, the greater the likelihood of variability under the conditions of this test.[7]

IN RAPIDITY

Rapidity in a method is almost as important as a minimum of random error. The less time required for each quadrat, the greater the number of quadrats that can be examined, and the more reliable the resulting average will be. Moreover, the more rapidly the examinations can be made, the less the data will be influenced by changes in the vegetation with season. This is an especially important consideration where, as in the short-grass region, field work may be seriously curtailed by summer drought.

TABLE 9.—*Average field time per trial and average office time required for compilation* [1]

Method	Quadrat 1			Quadrat 2			Quadrat 3		
	Field	Office	Total	Field	Office	Total	Field	Office	Total
	Man-minutes	*Man-minutes*	*Man-minutes*	*Man-minutes*	*Man-minutes*	*Man-minutes*	*Man-minutes*	*Man-minutes*	*Man-minutes*
Pantograph-chart	191	120	311	160	104	264	239	175	414
Density-list	62	5	67	45	5	50	51	5	56
Point-analysis:									
400 per meter [2]	58	3	61	37	3	40	48	3	51
800 per meter [2]	72	3	75	48	3	51	58	3	61

[1] Quadrat 1=0.5 m.[2]; quadrats 2 and 3=0.25 m.[2] each.

In the field a record was made of time consumed by each trial, and in the office, of the time required for its compilation. The averages, given in table 9, show that the chart method is 4 to 8 times as costly in total time as the other two.[8] In point of field time, a unit area of quadrat 3, which had about three times as much vegetation as quadrat 1, took about two and a half times as long to chart—that is to say,

[7] The explanations in this paragraph were tested with the aid of the field records. Inasmuch as this test may be of interest in application of the point-analysis method for studying the distribution of vegetation, it will be described.

Considering only the results of projections along the axis of the rack, occurrences of two hits together, two misses together, or a hit and a miss together were tallied. The frequencies of these occurrences were then compared with the frequencies which would have occurred if hits and misses had been distributed completely at random. Random distribution is given by weighing the expansion of $(p+q)^2$ by the proportion of the number of hits (p) and misses (q, where $q=1-p$) to the total number of trials. The term p^2S (where S is the total number) gives the number of expected hits, q^2S the number of expected misses, and $2pqS$ the number of expected hits and misses. The last four point-analyses (800 points per square meter) on each quadrat were used for the test. The averages of 20 deviations, observed minus expected, and their standard errors are as follows:

Quadrat	Miss and miss	Hit and hit	Miss and hit
1	−0.738±0.454	*+0.890±0.283*	−0.153±0.634
2	*+.910± .388*	*+1.085± .370*	*−1.998± .695*
3	−.901± .574	−.174± .421	+1.074± .932

The probability that these departures may be due solely to chance may be found by using a table of t such as given by Fisher (*3*). It will be found that P for the values in italics is less than 0.05, and these differences may therefore be thought of as being consistent enough to be real. For quadrat 1 there is a marked tendency for hits to fall together, but this tendency does not seem to affect the random occurrence of misses together, or of misses and hits together. This indicates numerous small, scattered tufts. For quadrat 2 there is a marked deficiency of misses and hits, and a tendency for hits to fall together and for misses to fall together. This indicates fairly large tufts and bare spaces; the deficiency probably arises from this cause and also from a tendency of the grass to be concentrated around the edges of this quadrat. (A single hit in the middle of the quadrat gives rise to two occurrences, a miss-hit and a hit-miss, but a hit by the point at the end of the rack can result in only half this much credit). Since the departures for quadrat 3 are well within the limits of expectancy, it is to be concluded that the distribution of grass on quadrat 3 is not proved other than random.

[8] Operation of the pantograph requires two men, but in the list and point methods only one need be used. It should be noted that the trials and time estimates used in this test are on a two-man basis, and hence allow for the list and point methods a considerably greater number of man-minutes than are needed in actual field practice.

working time is roughly proportionate to density—whereas by the other two methods the dense quadrat took only a little more than half again as long as the sparse one. Compilation of the list and point records took in every case less, usually much less, than one-twentieth the time required for chart compilation.

IN CONSISTENCY AND RAPIDITY COMBINED

In the preceding discussion it has been shown that the methods have differing degrees of variability and require different amounts of time, both of which are costs. Assuming the familiar relation to hold, that the squared standard error of the mean equals the squared standard deviation divided by the number of observations, we may determine the relative efficiencies (*3*), or inverse relative costs, of the three methods. Table 10 gives the efficiency components and their product in relation to the variability and time for the list method.

Strictly on the basis of time, the chart method is much less efficient than the others, and on the basis of variability, it is much less efficient than the list method. In its relation to the point method, the variability-efficiency of the chart method shows an interesting change from quadrat 1 to 3. On the scattered vegetation of quadrat 1, it is greater than that of the lower point-analysis rate and about equal to that of the higher rate; on the grouped vegetation of quadrat 2 it is lower than on quadrat 1, although still greater than the efficiency of the lower point-analysis rate; and on the dense vegetation of quadrat 3, it is far lower than the efficiency of the point method at either rate.

TABLE 10.—*Combination of the cost factors, variability (s^2), and time (T), relative to those of the list method; all terms expressed inversely as "efficiency"*

Method	Quadrat 1			Quadrat 2			Quadrat 3		
	$\frac{1}{s^2}$	$\frac{1}{T}$	$\frac{1}{s^2T}$	$\frac{1}{s^2}$	$\frac{1}{T}$	$\frac{1}{s^2T}$	$\frac{1}{s^2}$	$\frac{1}{T}$	$\frac{1}{s^2T}$
Pantograph chart	36.9	21.5	7.9	27.0	18.9	5.1	19.5	13.5	2.6
Density-list	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Point-analysis (400)	13.0	109.8	14.3	19.3	125.0	24.1	105.8	109.8	116.2
Point-analysis (800)	36.5	89.3	32.6	44.1	98.0	43.2	177.5	91.8	162.9

When the two factors are combined, the chart method is seen to have between one-twelfth and one-fortieth the efficiency of the list method, its relative efficiency becoming less as the vegetation increases in density and complexity. Depending upon sampling intensity, the relative efficiency of the point method varies here from one-seventh to more than half again as much as that of the list method, and, in contrast to the relative efficiency of the chart method, increases with increasing vegetation density. The efficiency of the point method can be considerably increased on vegetation of low density by increasing the number of points; that is, the decrease in variability from doubling the number of points more than makes up for the increase in time cost. On vegetation of higher density this increase in efficiency is progressively less marked.

ADAPTABILITY TO VARIED USE

The merits of these methods should be examined also in the light of the principal uses to be made of them. If comparison is to be made of the effects of known grazing treatments upon short-grass range over a period of years, including a record of the amount and kind of vegetation resulting under each treatment, and if data are desired on such ecological problems as conditions which govern seedling establishment or competition between individual plants of different species, periodical mapping may be necessary, and the chart method is the appropriate choice. If, on the other hand, the principal object is to know accurately magnitude of changes, rather than detail of processes involved in them, a more rapid, more accurate means, such as the list method, is desirable.

The chart method, besides providing a kind of pictorial history, showing the location and shape of each plant in relation to all the others, permits correction of many misidentifications. Chart data, however, are not always expressed in consistent terms, so that if one wishes to speak of spot symbols in terms of area, he must use an arbitrary conversion factor.

The list method, while it proved most efficient in this study, may not prove so in general application unless its use is carefully controlled. Estimates without a sound standard of reference are likely to vary between wide, and even wild, extremes. Hence it is necessary, in applying the list method, to provide some means of standardization. In the present test standardization was achieved by all observers working together in preliminary trials, and their concept of plant density was probably strongly influenced by the use of the point method, which they considered to be a more objective method than the others.

The principle of the point method was tested during the winter prior to the present test on quadrat charts on which the areas of outlined vegetation had been determined. About 400 intersections of regularly spaced lines were adopted as points, and it was found that the percentage of points falling within outlines of the principal species agreed closely with the area percent of those species. Under necessity to prepare a quick summary of uncompiled chart areas later, the writer applied the same method and rapidly made compilations sufficiently accurate for the immediate purpose. Abell (*1*) has recently described an application of the same principle to determine the areas of irregular figures on maps.

Another possible use of the point method, not touched upon in this paper, is the direct determination of volume by the total number of hits, that is, hits at all distances above the ground (*7*, *8*).

The variability of any method is probably at a minimum on an unobstructed quadrat such as the ones used in the present test. On many short-grass ranges, inclusion of cactus and sagebrush is unavoidable if the quadrats are intended to be truly representative. These plants interfere with operation of the pantograph and often require that the density-list frame be held at some distance from the ground. Tests made in the summer of 1937 showed that when the density-list frame is raised 7 inches off the ground, the variability of repeated estimates is markedly increased. Provided that sufficiently long sliding pins are obtainable, the point method is probably superior to the others under such conditions.

The three methods are capable of improvement in varying degree. A more rigidly constructed pantograph would reduce some though not the most important errors of the chart method. Doubtless, greatest improvements are possible in the point method, by using better sighting devices to minimize the number of doubtful hits, by using longer pins which slide more smoothly, with finer harder points, and by reducing the awkwardness and weight of the apparatus. The apparatus as used in this comparison was bulkier than that used by New Zealand workers, but the sharpened uprights of the instrument used by Levy and Madden (*8*), when repeatedly driven into the soil in an arid climate, probably would affect the quadrat environment seriously. The even simpler device diagramed by Fenton (*2*) has a similar objection and seems less adapted to precise work.

SUMMARY AND CONCLUSIONS

Three methods of quadratting short-grass vegetation—the pantograph-chart, density-list, and point-analysis methods (referred to as "chart," "list," and "point")—were tested on three typical short-grass quadrats, of low, intermediate, and high density. Five trained observers used each method four times on each quadrat, except that the point method was used six times at two different intensities. A 2-week period was required for the comparison, during which, it was concluded, no appreciable changes in the vegetation took place.

On an average, the methods reflected the marked differences in grass area between quadrats similarly, although with differing absolute values.

With all methods, consistent differences between observers were most evident on the quadrat with grass of highest density and most matted habit.

One observer, it was found, may record consistently greater areas by one method than by another, and another observer may record lesser areas by the first method and greater areas by the second; thus there may exist an interaction between observer and method.

In contrast to consistent differences between the results of different observers, inconsistencies, sometimes of considerable magnitude, appeared within the work of a given observer, in spite of elaborate precautions in training and standardization.

Areas by the chart method tended to be 50 percent greater than areas by the other methods, and the chart method proved to be less consistent than the list method on all quadrats and more consistent only than the lower-rate point method on the low- and medium-density quadrats. Since it required much more time than the list and point methods, its net efficiency, within the limits tested, varied from one-half to less than one-fiftieth of theirs.

Areas by the list method tended to be similar in magnitude to those by the point method, which may be due to preliminary standardization practice. The list method gave more consistent results than the others (except for the point method on the high-density quadrat). It required about the same amount of time as the point method. Its net efficiency was much higher than that of either of the other methods on the low- and intermediate-density quadrats, but lower than that of the point method on the high-density quadrat.

The two components of variation in the point method, sampling error and personal bias, were of about the same order of magnitude in this test. Although the points are not projected at random, one may arrive fairly close to any desired accuracy within the limits tested by altering the number of projections in accordance with sampling theory. As a corollary, since the method is a rapid one, its efficiency can be increased by increasing the number of projections. The benefit of such an increase was most marked with vegetation of low density.

In view of the results of this comparison, it is suggested that for estimating area of short-grass vegetation on intensively studied, permanent quadrats which are intended to sample the effects of grazing treatments, the density-list method, carefully standardized, be applied. The point-analysis method, pending its further development, may well be used for training and standardizing observers in the density-list method. The pantograph-chart method should be reserved for those studies in which the greatest need is a detailed graphic record of the vegetation.

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